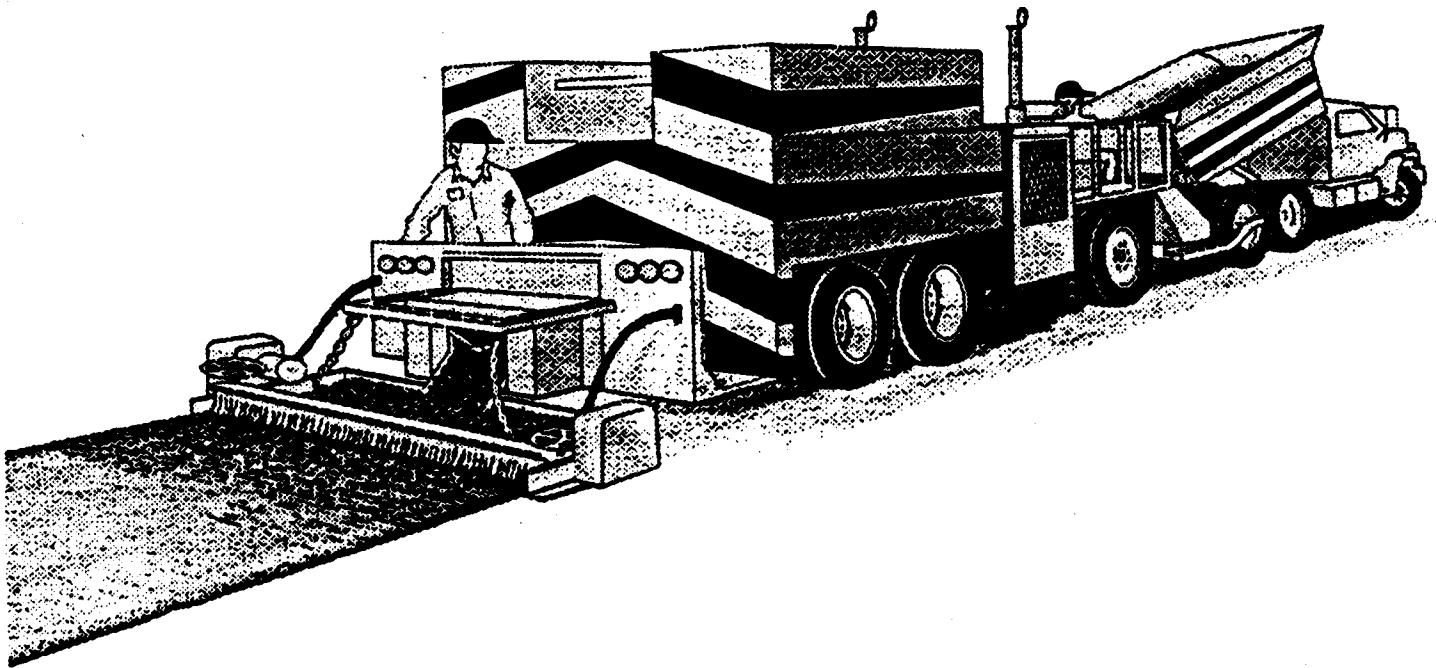




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An Overview of Surface Rehabilitation Techniques for Asphalt Pavements



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SURFACE REHABILITATION TECHNIQUES FOR ASPHALT PAVEMENTS

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ABSTRACT

As more and more higher volume roads reach their terminal serviceability, it is becoming increasingly important to find ways that help extend pavement service life in the most cost effective manner. One way to accomplish this is through the increased use of relatively low cost surface rehabilitation techniques that help improve the functional condition of the pavement.

Nearly all highway agencies use some kind of conventional surface rehabilitation/maintenance technique (such as seal coats, chip seals, and thin overlays) to maintain and even extend the service life of their asphalt pavements. The application of these techniques, however, has generally been limited to only low volume roads. On occasion a State may use a particular surface rehabilitation technique to address specific distress or as a short term fix on the more heavily travelled routes. The follow-up evaluation and performance documentation, however, is not always done.

During 1990, several preventive maintenance treatments including slurry seals, chip seals, and thin hot mix overlays were applied to the existing pavements under the Strategic Highway Research Program's specific pavement studies experiment entitled, "Flexible Pavement Treatments" (SPS-3). The treatments were applied throughout the United States and Canada to evaluate the effectiveness of maintenance strategies on pavement service life. A total of 81 test sites were selected to cover various climates and pavement conditions as well as moderate to heavy traffic volume roads.

Besides traditional surface rehabilitation techniques, many other approaches are now being pursued, particularly in Europe. These new techniques employ different additives/modifiers and aggregate composition as ways to attain increased pavement service life. This paper discusses various types of conventional surface rehabilitation techniques, along with many of the emerging techniques. The discussion includes information on usage, composition, construction, and (when available) performance and cost. This paper complements the work that SHRP has undertaken in this area.

The compilation of such information should assist the designer (or manager) when selecting the type of rehabilitation/maintenance technique for higher volume roads to meet both the system need (budget) and project performance criteria.

SURFACE REHABILITATION TECHNIQUES FOR ASPHALT PAVEMENTS

INTRODUCTION

A seal coat or chip seal is an application of a thin (usually less than 25 mm or 1 in thick) layer of asphalt, with or without aggregates, to a roadway surface to restore its characteristics, such as skid resistance, ride quality, and water proofing of the underlying layer. Thin hot mix asphalt surfacings, with thicknesses of 12.5 to 37.5 mm ($\frac{1}{2}$ to $1\frac{1}{2}$ in), are also effective and used for similar purposes. Generally, no structural improvement is developed in the pavement through the application of these surface rehabilitation techniques. Accordingly, these should be considered for only those pavements that possess the necessary remaining strength to support the design vehicular loads.

While many of these surface rehabilitation techniques are routinely used by State highway agencies, their use on high volume roads is fairly limited. Some reasons for this lack of use are (1) anticipated short life expectancy, (2) vehicular damage, (3) traffic disruption, (4) lack of performance and cost data, (5) improper timing and usage, and (6) lack of technology sharing. Many of these problems can be addressed by proper pavement evaluation, adequate design and construction procedures, follow-up evaluation and performance documentation, and effective technology sharing.

With some of the above goals in mind, several preventive maintenance techniques including slurry seals, chip seals, and thin hot mix overlays have been constructed under the Strategic Highway Research Program's (SHRP) SPS-3 experiment, "Flexible Pavement Treatments." The purpose of this SPS experiment is to evaluate effectiveness of various preventive maintenance treatments in prolonging the life of pavements; to evaluate cost effectiveness of these treatments; and to develop information on the most effective timing of application of these treatments.

Surface rehabilitation techniques are used for one or more of the following functions:

- Improved pavement performance by providing a smooth surface that affects not only the riding comfort but also the road user costs. Smooth surfaces decrease vehicle maintenance costs, fuel costs, and travelling time. Noise is another important functional condition that is affected by the surface quality.
- Enhanced safety by providing a skid resistant and/or rut-free surface.

- Extended service life by providing a renewed waterproof surface and protection from aging, oxidation deterioration, and traffic abrasion.

A particular surface rehabilitation technique may not achieve all of the above functions; however, by achieving even a few, a surface technique may significantly extend the service life of the pavement and will provide the user more consistent pavement performance. Consequently, these relatively low cost techniques should be considered for preventive maintenance or surface rehabilitation strategies.

In addition to surface treatments and thin overlays, pavement surface recycling is also considered an increasingly viable surface rehabilitation technique. This paper focuses only on the surface seals/treatments and thin hot mix overlays with particular emphasis on their application to higher volume roads.

OBJECTIVES & SCOPE

The primary objective of this report is to present an overview of the various surface rehabilitation techniques currently used in the United States and in Europe and to serve as resource document for the pavement designer/manager when considering preventive maintenance or surface rehabilitation strategies.

This overview consists of the following:

- A general discussion of the purpose and usage of various techniques.
- A brief discussion of mix composition and construction.
- An assessment of the effectiveness of the various techniques in terms of their relative performance, costs, and limitations.

TYPES OF SURFACE REHABILITATION TECHNIQUES

Surface rehabilitation techniques can be grouped into three types:

- A. Thin Seals/mixtures** (e.g., fog seals, slurry seal, microsurfacing)
- B. Chip Seal Coats** (e.g., single & multiple layer chip coats)
- C. Thin Hot Mix Overlay** (e.g., Open graded and dense graded courses)

A. THIN SEALS/MIXTURES

Fog Seal

Fog seals are the application of diluted asphalt emulsion without an aggregate cover.

Purpose: Its purpose is to seal the surface and provide some enrichment of oxidized asphalt cement (AC) surfaces that become dry and brittle with age, and to prevent raveling of chip seals and pavements laid in the late fall [1]. Some fog seals are also used to rejuvenate AC surface. Their primary use on high-volume roads has been to prevent raveling of open graded surface or to maintain shoulders along mainlines and provide delineation between the mainline pavement and the shoulder.

Application: Generally, anionic or cationic slow or medium setting type emulsions are used for fog seals because they can be applied in a coverage that flows easily into fine cracks and small voids.

The emulsion is often diluted with equal parts water for better control of the application rate which is usually kept rather low, 0.45 to 0.68 l/m² (0.1 to 0.15 gal/yd²), to prevent splashing and a decrease in skid resistance [1]. These seals are used only where the existing surface is sufficiently porous to absorb a substantial portion of the emulsion. The fog seal should be applied when surface temperature is above 16°C (60°F), and there is no threat of rain.

Traffic Control: Traffic should be detoured until the emulsion cures. Under normal conditions, 2 hours or less is sufficient [1].

Cost: A price range of \$0.12 to \$0.15/m² (\$0.10 to \$0.13/yd²) is fairly common for a fog seal application.

Limitations: Fog seals are not effective for long-term crack sealing. In addition, pavement friction may be reduced until traffic wears some of the asphalt from the surface. Under adverse weather conditions it may be several hours before a road can be opened to traffic.

Sand Seal

Sand seal is an application of asphalt followed by a sand cover aggregate.

Purpose: This seal serves the same function as a fog seal, but it provides better surface friction.

Application: Usually rapid setting (anionic or cationic) or medium setting (anionic or high float) emulsions are used. The rate of emulsion application varies from 0.68 to 0.90 l/m² (0.15 to 0.2 gal/yd²) depending on pavement texture, local conditions, and traffic [2]. The emulsion spray is followed by about 5.4 to 8.1 kg/m² (10 to 15 lb/yd²) of sand or stone screenings. The sand should be 6.35 mm (¼ in) sieve size or smaller. For maximum adhesion, the sand can be applied immediately or for better texture, can be applied after the emulsion has started to break on the top of the rocks in the pavement. Pneumatic tire rolling is desirable.

Traffic Control: Traffic should be kept away from the surface until the seal is set. Under normal conditions, 2 hours are sufficient.

Cost: The cost of a sand seal application often ranges from \$0.30 to \$0.48/m² (\$0.25 to \$0.40/yd²).

Limitation: This seal has the same limitations as a fog seal except that a sand seal may not provide the distinct delineation that a fog seal does, depending on aggregate color.

Slurry Seal

A slurry seal is a mixture of well-graded, fine (sand size) aggregate, mineral filler (in most cases), and dilute asphalt emulsion. A single course is usually applied in thicknesses of 3 to 6 mm (1/8 to ¼ in). A standard single application slurry seal was applied to 81 test sites throughout the United States and Canada under SHRP's SPS-3 experiment.

Purpose: Slurry seals are effective in areas where the primary problem is excessive oxidation and hardening of the existing asphalt. They are used for sealing minor surface cracks and voids, retarding surface raveling; delineating different pavement surface areas; and, with proper aggregate, improving surface friction characteristics.

Application: Aggregate, water, emulsion (slow or quick setting), and additive are proportionately mixed together in a slurry machine on the job site and immediately applied to the paved surface with a squeegee device. Additives such as portland cement, hydrated lime, or aluminum sulphate liquids are often used in small quantities as stabilizers or chemical modifiers to add in setting the slurry.

There are three types of slurry seal, with different applications appropriate for each one [3]. The three types primarily differ by the gradation of the aggregate used. Table 1 presents slurry mixture characteristics as recommended by the International Slurry Surfacing Association (ISSA). Only types II and III are used where moderate to heavy traffic is present, in order to correct raveling and obtain maximum skid resistance and an improved wearing surface.

TABLE 1. SLURRY MIXTURE CHARACTERISTICS

Type of Slurry	I	II	III
Sieve Size mm (in)		Percent Passing	
9.5 (3/8)	100	100	100
4.75 (No. 4)	100	90-100	70-90
2.36 (No. 8)	90-100	65-90	45-70
1.18 (No. 16)	65-90	45-70	28-50
0.600 (No. 30)	40-65	30-50	19-34
0.300 (No. 50)	25-42	18-30	12-25
0.150 (No. 100)	15-30	10-21	7-18
0.075 (No. 200)	10-20	5-15	5-15
Residual Asphalt, % weight of dry aggregate	10-16	7.5-13.5	6.5-12
Application Rate, kg/m ² (lb/yd ²)	3-5.5 (6-10)	5.5-8 (10-15)	8 (15) or more
General Usage	Crack sealing (low traffic areas)	Correct raveling, oxidation (moderate to heavy traffic)	Fills minor surface irregularities. Restores surface friction. First course in multicourse applications for heavy traffic

Generally, it is not necessary to roll a normal thickness of slurry seal except in areas subjected to abrasion caused by severe steering, braking, or acceleration. These areas may be densified by a 4.5 Mg (5 tons) pneumatic tire roller. The rolling can start as soon as clear water can be pressed out of the slurry mixture with a piece of paper without discoloring the paper [2].

Traffic Control: A curing period is necessary before allowing traffic on the slurried surface. In warm weather, 2 hours is typical; in cool weather, 6 to 12 hours or more may be necessary.

Cost: A price of \$0.84 to \$1.14/m² (\$0.70 to \$0.95/yd²) is fairly common for a single application, but cost could vary depending on the quantity, location, and thickness. A two-course application will be nearly twice the cost of a single application.

Performance: Slurry seals are considered to have a nominal life of 3 to 5 years on roads with moderate to heavy (ADT of 5000/lane) traffic. This compares to an average life of 7 to 12 years for a 37 mm (1½ in) asphalt overlay. Slurry seal sections placed on 81 test sites under SPS-3 are now being evaluated under the SHRP's Long Term Pavement Performance (LTPP) evaluation program.

Limitation: Slurry seals generally do not perform as well as traditional chip seals if the underlying pavement surface is cracked and moves under traffic. In addition, slurry seals require a longer curing time than chip seals.

Micro-Surfacing

Micro-surfacing is a polymer-modified cold paving slurry seal system. This system was developed in Germany in 1976, and since then has been used in Europe to fill wheel ruts and resurface major highways. This system was first used in the United States in 1980, in Kansas. Since then many other States have either used this treatment or are considering its use for certain pavement conditions. In addition, some States have constructed the micro-surfacing test sections under the SPS-3. Ralumac, the German micro-surfacing product, is widely used in U.S. along with some other systems. User States have now developed specifications for micro-surfacing.

Purpose: Its most common uses are rut filling, minor leveling, and restoration of skid resistant wearing surfaces. The polymer-modified slurry cures and develops strength faster; therefore, it can be placed in greater thicknesses.

Application: Microsurfacing consists of a mixture of latex-modified emulsified asphalt, mineral aggregate, mineral filler, water, and additives. The modifier used in this treatment could be either natural latex or synthetic latex. Most State specifications require that the mixture include 82 percent to 90 percent aggregate and 2 percent to 4 percent latex polymer by weight of the asphalt used. The amounts of other constituents as a percentage of the dry aggregate generally are:

- 1.5 percent to 3.0 percent non-air entrained portland cement as mineral filler.
- 6.0 percent to 11 percent residual asphalt.

The optimum combination of component materials is determined by a mix design. The amount of the additives and the moisture content is determined in the field in order to obtain specified properties and consistency. The mineral filler, emulsifying agents, and polymer affect the breaking and curing of the mix.

The cold paving latex-modified asphalt emulsion is mixed with the aggregate and other additives in a traveling pug mill similar to, but larger than that of a regular slurry seal machine. For surface texturing, an adjustable width spreader box capable of spreading the mixture from 2.4 to 4.3 m (8 to 14 ft) wide is usually used. When filling ruts is the primary reason for using micro-surfacing, the favored method of placement is to use a drag box only slightly wider than the rut. Two sizes of rut filling boxes, i.e., 1.5 and 1.8 m (5 and 6 ft) wide, are commonly used. The Pennsylvania Department of Transportation (PennDOT) has reported that this treatment may fill ruts up to 50 mm (2 in) [5].

After a rut filling application has fully cured, a full lane thin application can be applied to give uniform surface friction. It has been reported that wheel ruts less than 12.5 mm (½ in) deep can be filled with a full width single application. No roller compaction is required for either rut filling or surfacing. However, areas not to be exposed to traffic should be rolled with a 9.1-Mg (10-ton) pneumatic tire roller. A tack coat is not required unless the surface to be covered is extremely dry and raveled or is concrete. If required, a tack coat of emulsion should be applied at a rate of 0.16 to 0.32 l/m² (0.05 to 0.10 gal/yd²). The tack coat should be allowed to cure before application of micro-surfacing.

The application rate for retexturing seals on high volume roads ranges from 8.1 to 19 kg/m² (15 to 35 lb/yd²) depending upon the surfacing thickness. Generally, 8.1 to 16.2 kg/m² (15 to 30 lb/yd²) is used for layer thicknesses of 6.3 to 12.5 mm (¼ in to ½ in) for a single application. For wheel ruts, the application rate varies according to the rut depth. Aggregate gradations used by different States normally follow ISSA recommendations for slurry types II and III (see tables I, 2) with minor variations. The microsurfacing is spread only when the road surface temperature is at least 10°C (50°F) and rising, and the weather is not foggy or rainy.

Traffic Control: The quick curing times allow traffic on the surface soon after application. A surface can generally be opened to traffic in about 1 hour after application in 24°C (75°F) temperature and 50 percent humidity [4]. The application rate of the mixture and the amount of the additive used to control breaking and setting time also influence the curing period. Incidences of either tearing or rutting of the mat under traffic turning maneuvers have been reported even when the mat was approximately 1 to 2 hours old. Reference 5 speculates that these problems may be due to local ambient conditions, particularly low humidity and very hot weather.

Cost: The unit cost of microsurfacing is often three times or more the unit cost of hot plant mixes. A price range of \$90 to \$130/Mg (\$82 to \$120/ton) or alternatively a price range of \$1.05 to \$2.00/m² (\$1.00 to \$1.80/yd²) for normal applications (9.5-12.5 mm thick) has been reported by some States. The costs vary because of the location and the condition of the pavement and the application thickness.

The unit price difference, when compared to conventional hot mix overlays, is offset by the fact that micro-surfacing can be applied as a very thin treatment. The use of micro-surfacing also has the benefit of not requiring any adjustments to appurtenances such as curbs, shoulders, drainage inlets, and guardrails. Micro-surfacing also offers considerable cost reductions in total construction costs (because of ease in traffic control and thin application) for the certain applications.

Performance: Based on the performance of various projects in Arkansas, Oklahoma, Ohio, Pennsylvania, Texas, and Virginia, it appears reasonable to expect at least 4 to 5 or more years of service from micro-surfacing. However, more performance information is desired on this treatment.

Rut Repair– Micro-surfacing appears to perform well as a rut filler. While ruts up to 50 mm (2 in) deep have been filled, on most projects thicknesses varied from about 3.18 mm (1/8 in) between wheel paths to about 19 mm (3/4 in) in the rutted wheel paths. The PennDOT and the Oklahoma Turnpike Authority report good rut resistance for up to 3 years. The Arkansas State Highway Transportation Department and the Texas Department of Transportation experiences are also positive in this regard [5].

Surface Friction– Based on the available data from Texas, Arkansas, Pennsylvania, Oklahoma, and other States, it seems that this treatment improves the skid resistant characteristics of the surface [5]. The extent of improvement varies from State-to-State and project-to-project depending largely on the quality of the aggregate. Improvements of up to 35 to 40 in friction values have been reported.

Crack Repair–The growing consensus is that polymer modified slurry seals are not very effective in controlling reflective cracking [5].

Limitations: Micro-surfacing requires special paving equipment with a more powerful and faster mixer than used for slurry seals. An experienced contractor is also desirable. Fast setting characteristics of these materials sometimes hinder construction of acceptable transverse and longitudinal joints. Microsurfacing mixes are also more aggregate-specific than a normal slurry seal because of chemically triggered, quick reactions.

Slurries and Modified Slurries in Europe

Slurry seals have been used in Europe as one of the surface maintenance techniques since 1920. Following the progress made in the manufacturing of engineered binders in the late 1970s, the modified slurry seals (micros or cold microagglomerates in Europe) experienced increased use throughout Europe, especially on the heavily traveled roads (ADT 10,000-40,000). Spain, Germany, and France are European leaders in the use of slurries and modified slurries which are applied in both single and double layers. Modified slurries are used for profiling, rut filling, and enhancement of skid resistance on all kinds of roads. The Rut filling application, however, is generally limited to those ruts which are not deeper than 30-40 mm (1.2-1.6 in.) and are the result of mechanical deformation.

In Europe, aggregate types and mixes generally refer to the maximum and minimum nominal stone size in the aggregate gradation. The nominal maximum size of the aggregate is approximately the smallest sieve size through which nearly all (85 to 100 percent) of the aggregate passes. For example, type 0/3 (or 0 to 3 mm size) means that 3 mm is the nominal maximum aggregate size in the mix and that 85 to 100 percent of the material would pass through a 3 mm sieve. Larger gradings of 0/8 to 0/12 are usually required for major highways. Table 2 presents some examples of U.S. and European modified slurry systems [4,6].

Latest Developments in Europe

Incorporation of fibers in the modified slurries is the latest innovation [6]. France and Spain are the lead countries in this respect. France uses a gap-graded mixture with organic fibers (0.1 to 0.2 percent by weight of aggregate, and 4 to 8 mm in length) to obtain better skid resistance and surface drainability. Fibers are used to increase the viscosity of the emulsion, making it possible to place gap-graded mixtures without any segregation.

In Spain, incorporation of fibers is thought to achieve skid resistance and improved flexibility to retard surface cracking. Fiber usage in Spain varies from 0.3 to 1.0 percent of the weight of the aggregate.

A technical working group, WG2-CEN, European Committee for Highways, has now been established for the purpose of revising and standardizing the highway specifications for each of the member countries.

TABLE 2. COMPOSITION OF U.S. AND EUROPEAN MODIFIED SLURRY SEAL SYSTEMS

Country	US	Germany	Denmark	Italy	Netherlands
Type	III	0/8	0/8	0/9	0/8
Sieve Size	% passing				
mm (in.)					
9.5 (3/8")	100			85-100	95-100
8.0 (5/16")		90-100			90-100
6.25 (1/4")			93		67-90
4.75 (No. 4)	70-90	65-85			
4.0 (No. 5)				60-85	55-80
2.36 (No. 8)	45-70				
2.00 (No. 10)		45-65	50	36-55	40-60
1.18 (No. 16)	28-50				
0.60 (No. 30)	19-34				
0.40 (No. 40)				14-28	
0.30 (No. 50)	12-25				
0.25 (No. 60)			17		
0.20 (No. 70)					
0.15 (No. 100)	7-18				
0.075 (No. 200)	5-15	6-12	3	4-8	2-10
Residual Asphalt (% of mix.)	** 5.5-9.5	5-7	5.3	5.5-7.5	*** 5-7
Application Rate kg/m ² (lb/yd ²)	8.1-16.2 (15-30)	25-30 (46-55)	>16-18 (>29-33)	15-25 (28-46)	
* ISSA type	** % of dry aggregate	*** mostly conventional emulsion			

B. CHIP SEAL COATS

Chip seal

A chip seal is an application of asphalt followed with an aggregate cover. This type of surface treatment can consist of single or multiple layers ranging in thickness from 9.5 to 37 mm (3/8 to 1½ in). Two layers are referred to as a double and three as a triple chip seal coat. In multiple chip seals, smaller aggregate sizes are used in each successive layer. For example, in a double chip seal, the largest size stones are placed in the first course and these determine the surface layer thickness. The second course serves to fill the voids in the first course. When using multiple layers, the first layer should be cured before the application of the second layer. A standard chip seal (3/8" - #10) was placed on 81 test sites under SPS-3. Some States also chose to construct additional chip seal sections using different gradation and binder.

Purpose: On low volume roads, chip seals can be used as a wearing course or as the only surface course. Recently, this treatment has also been used on higher volume roads (volume greater than 5,000 vehicles/lane/day) because of its ability to waterproof the surface, provide low severity crack sealing, and improved surface friction. The possibility of loose chips and traffic disruptions, however, has limited the application of chip seals on high volume facilities. A study has concluded that use of chip seals on high traffic facilities in the United States is limited to 10 States [7]. The use of precoated chips is more suitable for high volume roads. However, only six States (Illinois, Oregon, Pennsylvania, Texas, Utah, and Virginia) routinely use precoated aggregates [8].

Application: Application usually consists of a spray of rapid setting type emulsion (or asphalt cement, cutback) at a relatively high rate, followed immediately by an application of aggregates. Emulsions are preferred over asphalt cements and cutbacks as these can be used with damp aggregates and meet environmental requirements. Asphalt application rate is determined to achieve an embedment of 50 to 70 percent. Maximum aggregate sizes usually range from somewhat coarser than sand up to 19 mm (3/4 in). One-size aggregates are preferred because they develop better interlocking and provide maximum contact between the tire and the surface. Table 3 gives example of quantities of asphalt and aggregate for single chip seals applications with respect to the commonly used aggregate sizes [2]. If the precoated aggregate is used, an asphalt content of about 0.75 to 1% by weight of the chippings, and 90% or more coating is desired [8].

The cover aggregate is rolled immediately after spreading with either a steel-wheeled tandem or rubber-tired roller to ensure maximum embedment. The rubber-tired roller is often thought to be the best all-purpose roller for chip seal construction. The minimum recommended pavement temperature required prior to asphalt application is 15.5°C (60°F).

TABLE 3. QUANTITIES OF ASPHALT AND AGGREGATE FOR SINGLE CHIP SEAL APPLICATION

Nominal Size of Aggregate mm (in)	Quantity of Aggregate kg/m ² (lb/yd ²)	Quantity of Emulsion l/m ² (gal/yd ²)
19-9.5 (3/4-3/8)	22-27 (40-50)	1.8-2.3 (0.4-0.5)
12.5-4.75 (1/2- No. 4)	14-16 (25-30)	1.4-2.0 (0.30-0.45)
9.5-2.36 (3/8- No. 8)	11-14 (20-25)	0.9-1.6 (0.20-0.35)
4.75-1.18 (No.4- No. 16)	8-11 (15-20)	0.7-0.9 (0.15-0.20)

Notes: (1) The asphalt application rates in the above table are for emulsions. These rates may vary if other asphalt types (i.e., asphalt or cutback) are used; (2) The lower binder rates should be used for aggregate having gradations on the fine side of the specified limits; (3) Aggregate and binder rates should be adjusted according to the local experience and existing condition of the pavement.

There are several methods for designing multiple chip seals, including methods by the Asphalt Emulsion Manufacturers Association and Asphalt Institute. The Texas Transportation Institute's research report 448-1F also discusses design and construction of multiple seal coats.

Traffic Control: The road may be opened to traffic after rolling is completed; however, traffic speed on the newly placed surface should be limited to about 20 mph for a period of 2 hours (1 hour for asphalt cement in cold weather; 3 or more hours for emulsions in humid weather) [9]. On high volume roads, slow moving controlled traffic may be required for longer periods or alternatively additives can be used to decrease the curing time.

Cost: Chip seals are one of the most economical surface rehabilitation techniques, considering their service life versus cost. Single application chip seals cost more than fog or sand seals but are generally less expensive than slurry seals. A 1988 survey by the American Association of State Highway and Transportation Officials (AASHTO) indicates an average price of \$0.90/m² (\$0.75/yd²) for a single chip seal application [10]. Double chip seals are about 1½ times the cost of a single chip seal [2].

Performance: Chip seals have been used on highways with traffic volumes in excess of 5,000 vehicles per day with a performance life of about 4 to 7 years. A Texas report indicates the average life of chip seals in Texas as 6 to 7 years for traffic volumes as high as 4,000 vehicles per day per lane [9]. Washington State DOT

expects 5-7 years of service life from their polymer modified chip seal projects on high volume roads. Double chip seals are reported to give more than twice the service life of a single chip seal. In Australia and New Zealand, double chip seals are designed for 10 years of service life for pavements which carry traffic volumes up to 20,000 vpd [11]. Several chip seal projects were also constructed under the SHRP SPS-3 Project. The performance evaluation of this treatment is ongoing under the SHRP-LTPP program. Preliminary indications confirm that timing of chip seal application is critical to its performance and cost effectiveness.

Limitations: The best way to achieve surface sealing and skid resistant surfaces is to use large, one-sized aggregates, generally of 12.5 mm (½ in) or greater. However, availability of one-sized chips is not always assured and if large size stones (greater than 12.5 mm) are used, windshield damage can be a major problem, especially if the stone chips are not adequately embedded in asphalt and the excess stones are not swept. Increased tire noise is also reported for these treatments. Other problems include prolonged traffic control, flushed pavements, and potential for early failure due to inadequate design and construction practices.

Sandwich Seal

The sandwich seal or "French Dressing" is a double application chip seal constructed by using only one application of binder. In this process, one course of large aggregate is spread first, followed by the emulsion application, and then a second course of smaller aggregate. The term "sandwich" is used because the asphalt application is in the middle.

Purpose: This process recently introduced in France was developed as a means of sealing high traffic pavements and flushed pavements. Improved skid resistance is also achieved by this technique.

Application: A sandwich seal uses many construction procedures similar to those involved in a normal chip sealing operation. In summary, one-sized 4.75 to 9.5 mm (No. 4 to 3/8 in) washed chips are spread on a clean and dry pavement [7]. The application rate is kept at approximately 80 percent of the amount needed to provide coverage at one stone thickness (several methods are available to determine one-stone thick coverage). A lightweight steel roller may be used to "seat" the first application of chips. An asphalt binder is then applied at a rate of 1.2 to 1.5 times the amount for a conventional single course treatment. This is followed by the application of a second course of one-sized 2.36 to 4.75 mm (1/8 to No. 4) washed chips. Finally, a slow-moving pneumatic roller is applied to the completed application.

Cost: Since only one application of asphalt is required, it is generally more economical (\$1.20-\$1.30/m² or \$1.00-1.10/yd²) than a double chip seal.

Performance: This seal provides an increased service life which is typically the same as a double chip seal.

Limitation: Clean aggregate is essential in this type of application unless high float emulsion is used.

Cape Seal

A cape seal is a chip seal topped with a slurry seal. The name is derived from it being originally developed in the Cape Province of South Africa.

Purpose: A cape seal produces a seal with no loose cover stones. This seal may be best suited for roads with high traffic volumes. It provides a dense surface with improved skid resistance and a relatively long service life.

Application: A single course chip seal is laid in the conventional manner. After the chip seal has cured, the slurry seal is applied over the chip seal to fill the voids between the cover stones. A cure time of 4 to 10 days between placement of chip seal and subsequent slurry seal application should be provided for, during which time the surface should be regularly broomed for better adherence of the slurry. For a 12.5-mm (½-in) thick layer, the approximate quantities would be emulsion layer of 1.4 to 2.0 l/m² (0.3 to 0.45 gal/yd²); chip spread of 14 to 16 kg/m² (25 to 30 lb/yd²); and slurry mixture (usually type I) of 3 to 5.5 kg/m² (6 to 10 lb/yd²) [2].

Traffic Control: A curing period similar to a slurry seal application is required. In warm weather, 2 hours is typical, and in cool weather 6 to 12 hours or more may be necessary.

Cost: This treatment has a higher initial cost (\$1.55-\$2.00/m² or \$1.30-\$1.70/yd²) because it combines the cost of a chip coat and slurry seal.

Limitation: A longer construction time is required.

Rubberized Asphalt Chip Seal

A rubberized asphalt chip seal is similar to a regular chip seal surface treatment, except that the asphalt binder is replaced with a blend of ground tire rubber (or latex rubber) and asphalt cement. The rubber additive is reported to enhance temperature susceptibility, elasticity, and adhesion characteristics of the binder. Temperature susceptibility and elasticity influence the binder's ability to resist the stresses induced by climate and traffic. A number of States routinely design and apply this system as a preventive maintenance tool. Arizona, California, and Texas are lead States involved with using this system.

Purpose: This treatment is among the best for bridging and sealing cracks. It produces either a stress-absorbing membrane layer (SAM) or, when used in conjunction with a thin hot mix asphalt overlay, a stress-absorbing membrane interlayer (SAMI). This treatment can resist and delay the development of reflective cracks when the cracks are generally inactive, like low severity fatigue cracking and closely spaced random or block cracking. This seal can not resist the amount of strain that is typical of major transverse thermal cracks in AC pavements. As with any thin surface treatment, the existing pavement structure must be sound.

Application: The binder in this seal is asphalt rubber thinned with a diluent (usually a kerosene) approximately 5 to 7 percent by weight of the asphalt rubber binder. This improves its flow characteristics for spray application. The asphalt rubber is a mixture of 70 to 80 percent hot asphalt cement and 20 percent to 30 percent rubber, mixed at a temperature of about 350°F to cause a reaction. The cover aggregate is generally a uniform size 9.5 to 6.4 mm (3/8 in to 1/4 in) sieve size. The aggregate should be clean and compatible with the modified binder. Pre-heated precoated aggregate is preferred. If the aggregate is precoated (usually 0.3-0.5% by weight of AC), uniform coating of the aggregate should be checked. Typical application rates which have been used successfully are 2.7 l/m² (0.6 gal/yd²) of diluted asphalt rubber binder and 19 kg/m² (35 lb/yd²) of cover aggregate.

The construction of a rubberized chip seal is similar to any conventional chip seal. The major difference is the modified asphalt distributor. Rollers are used to properly embed the aggregate.

Traffic Control: The diluent chosen to reduce the asphalt rubber viscosity will affect the cure time. It is reported that asphalt-rubber binders can be used effectively to reduce the high flying chips even with limited traffic control [7].

Performance: The City of Phoenix, which has been a pioneer in the use of this system, now expects approximately 12 years of life from the SAM application [12]. Arizona, Texas, Nevada, Oregon, and California DOTs have several years of experience with this treatment.

Cost: The initial cost of this system is high [7]. The City of Phoenix reports the cost of this system as approximately two times that of a conventional chip seal [12]. In Arizona and California during the late 1980's the in-place cost for this system generally ranged from \$1.90 to \$2.30/m² (\$1.60 to \$1.90/yd²).

Limitation: Special equipment and contractors familiar with hot asphalt cement and asphalt-rubber seals are necessary to achieve success.

Chip Seal Systems in Europe

European chip coat systems for high volume roads are similar to U.S. systems except that chips are often spread over a layer of polymer modified binder. Furthermore, in Europe (particularly in France), the use of hot pre-coated chips is gaining more acceptance. At least one system in France also uses synthetic organic threads to strengthen the film of the modified binder for an improved resistance to reflective cracks.

Purpose: Pre-coated chip seals are used for the same purposes as traditional chip seals, but are more suitable for high volume roads because loose chips are minimized. These systems are reported to generate relatively lower rolling noise levels than conventional chip seals (77 dbA versus 79.6 dbA for conventional chip seals at 90 km/h [54 mph]) and good surface friction [13].

Application: A 6 to 10 mm grading size has been the most commonly used size, but in some cases, 4 to 6 mm or 10 to 14 mm grading sizes can be preferred. Aggregates are usually applied at a rate of 20 to 27 kg/m² (37 to 50 lb/yd²) for 6/10 aggregates. The rate of modified emulsion application usually varies from 0.8 to 2.0 l/m² (0.18 to 0.45 gal/yd²) depending on pavement condition, traffic, and thickness.

Traffic Control: A road can be opened to traffic as soon as the wearing course is rolled.

Performance: Some of these systems have been in use for a few years. While it is too early to draw conclusions, no major problems have been reported.

Limitations: Special equipment is required for many of the patented European chip seal coat systems.

Patented Chip Coat Products—France

Some of the chip seal systems currently used in France include: Novachip, Emulcol, Routochap, Filaflex.

Novachip consists of a layer of hot chips coated with asphalt and sand, spread over an elastomer or latex modified binder layer. This system is a proprietary product of the French company Scred Routes [13]. A single machine, specially designed for this system, completes the three operations of spreading the binder, applying the hot pre-coated chips, and smoothing the course.

Emulcol serves the same purpose as traditional chip seal except that it can be laid in cooler weather [14]. Both traditional cationic emulsion or polymer modified binders

are used. An experimental application of this system was completed in 1990 on a site in New York under the SHRP Program.

Routochap technique involves the application of a thick film of an elastomer binder (2.3 or 3.2 l/m² [.52 or .72 gal/yd²]) which is then covered with 6.3/10 or 10/14 type pre-coated chips. This system is a patented product of the French company Gerland Routes.

Filaflex is a chip system made up of a film of modified binder strengthened by continuous threads. In this system a binder application of 0.9 to 1.4 l/m² (0.2 to 0.3 gal/yd²) is followed first by synthetic organic threads at a rate of 0.05 to 0.15 kg/m² (.027 to .081 lb/yd²) and then by application of 4/6 or 6/10 aggregates. It is used for treating pavements with fatigue or shrinkage cracks. This system is a patented product of the French company Screg Routes.

C. THIN HOT MIX ASPHALT OVERLAYS

Open Graded Friction Course

Open-graded friction courses (also known as porous friction courses, PFCs, OGFCs, plant mix seals, or popcorn mixes) are normally less than 25 mm (1 in) thick and possess high percentages of voids (15 percent or more). A 1988 survey by AASHTO indicates that 27 States currently use OGFC, whereas 21 States have discontinued its use [10]. Some States have placed OGFC's test sections under SHRP's SPS-3 experiment.

Purpose: High voids in an OGFC allow water to drain through the mix and laterally to the side of the road. This rapid removal of water reduces the potential for hydroplaning and improves visibility by reducing tire spray. These mixes substantially improve the surface friction characteristics. They may also reduce the roadway noise which is a function of the air voids and the maximum stone size at the surface. Research by the Maryland State Highway Administration has shown a noise reduction of 3 dbA for OGFC compared with PCC pavement [15]. Results from various other studies show that a noise reduction of 3 dbA to 6 dbA can be achieved by using OGFCs.

Application: The FHWA and nearly all highway agencies have specifications for design and construction of OGFCs. The gradation of this treatment is characterized by an open-graded mix with a nominal maximum size of 9.5 mm (3/8 in), and a high proportion of single-sized aggregate, with about 2 to 5 percent passing 0.075 mm (No. 200) to reduce binder run-off and improve mix stability. An OGFC generally has a higher asphalt content than a dense grade mix. The gradation range for OGFC as recommended by the FHWA is given in Table 4 [16].

Rolling of an OGFC is generally limited to one or two passes of a 7.3 to 9 Mg (8 to 10 ton) static steel wheel roller to seat the mix. Since an OGFC is placed as a thin lift, it loses heat quickly. Accordingly, an OGFC should only be placed when the underlying pavement surface and ambient temperature have reached 16°C (60°F).

A fog seal is recommended to seal the underlying pavement [16]. For this purpose a 50 percent diluted asphalt emulsion may be applied at a rate of 0.23 to 0.45 l/m² (0.05 to 0.1 gal/yd²) [16]. A number of State and local agencies have used latex modified asphalt and other additives to improve OGFC performance; however, use of a modified binder in OGFCs is still rather limited in the United States. The use of a SAMI to level and seal the existing pavement under the OGFC is now being considered by some agencies.

Traffic Control: Road can be opened to traffic soon after the mix is rolled.

Cost: The average cost of conventional OGFCs has been reported to be about \$1.46/m² (\$1.22/yd²) [10].

Performance: These mixes have been reported to provide good performance for 8 to 11 years under a range of traffic conditions [10,16].

Limitations: Because of the open, porous structure of this mix, the OGFCs are susceptible to several types of distresses, including stripping; rapid formation of reflective cracks; and raveling, especially at intersections, ramp termini, and locations with heavy turning movements. These mixes also require special patching and repair techniques.

A good drainage system is necessary to remove surface water effectively and to prevent clogging of the voids. This may require milling or a light leveling course prior to the application of OGFC to provide a reasonable cross slope. Also, during winter, salt spreading is less effective because the salt does not accumulate at the surface but in the pores of the OGFC. This results in the need for more deicing chemicals to prevent ice build-up.

OGFCs (or Porous Asphalts) in Europe

The OGFCs have been investigated and widely used in Europe. In addition to reducing splash/spray and light reflectance and helping to maintain high friction levels between vehicle tires and wet pavements, OGFCs in Europe are increasingly recognized for their ability to decrease tire and vehicle noise by 3 to 4 db(A), compared to dense mixes [17].

When compared to OGFC applications in the United States, the European mixtures are generally coarser, 9.5 to 16 mm (3/8 in to 5/8 in), gap-graded, and contain more air voids (generally 20 to 25 percent). The layer thickness is normally 35 to 40 mm (1.4 in to 1.6 in), and in some cases 50 mm (2 in). Thicker layers are used to ensure high draining capacity and reduction in rolling noise and to preserve these properties over a longer period. Asphalt binder modifiers such as fibers and polymers (and sometimes rubber) are used to prevent runoff of the binder and/or to increase durability and aging resistance. Table 4 presents some of the characteristics of the U.S. and European OGFCs [17].

Cost: In Germany, OGFCs cost 100% more than conventional mixes; in France OGFCs with rubber modifier cost 20% more than conventional mixes (17,18).

Performance: Europe, OGFC surfaces are designed to provide an average service life of 10 to 12 years.

TABLE 4. COMPOSITION OF U.S. AND EUROPEAN OGFCs

Country	US (FHWA)	Sweden	France	Nether- lands	Spain	Switzer- land
Sieve Size	% passing					
mm (in.)						
25.0 (1")						
19.0 (3/4")						
16.0 (5/8")		90-100		95-100		95-100
12.5 (1/2")	100	70	100	75-90	70-100	75-90
9.5 (3/8")	95-100	36-42	85-90	55-70	50-80	50-80
6.25 (1/4")			24-28			
4.75 (No. 4)	30-50	20-24	20-22	20-35	15-30	15-40
2.36 (No. 8)	5-15	10-15	12-14	11-18	10-22	12-21
1.18 (No. 16)						
0.60 (No. 30)					6-13	7-13
0.15 (No. 100)						
0.075 (No. 200)	2-5	4-6	1-2	3-5	3-6	4-7
On-site Thickness (mm)	19	43	40	50	40	45
Top Size Aggregate (mm)	9.5	16	10	16	12	16
Asphalt (% of mix)	5.5-7.5	5-5.5	4.5-6.5	4-5	4.5	4-5
Voids %	15+	15+	20-25	15-25	20+	15-20

Notes: Mixes with pure asphalt have lower binder content (e.g., 4-4.5%) and the mixes with tire rubber have the highest binder content (e.g., 5.5-6.5%); when used fibers are usually 0.3-0.8% of the binder.

Proprietary Porous Asphalt Systems in Europe

Some porous asphalt systems include: Drainochape, marketed by Beugnet (France); Permflex, produced by Colas S.A. (France); and Drainor produced by Skanska AB (Sweden) [18].

Stone Matrix Asphalt

Stone matrix asphalt (SMA) is a relatively thin (12.5 to 40 mm [.49 to 1.56 in]) gap-graded, densely compacted, hot mix asphalt that is used as a surface course on both new construction and surface renewal. It is a mixture of asphalt cement, coarse aggregate, crushed/natural sand, and additives. These mixes are different from normal dense grade HMA mixes in that there is a much greater amount of coarse aggregate in the SMA mix. Germany, which is given credit for developing this application, uses it on major highways with heavy traffic volumes. A few experimental sections using this mix have now been constructed in the United States.

Purpose: This product was developed by the European contractors to provide a rut resistant wearing course and to provide resistance to the abrasive action of studded tires. According to European producers and users, this application also provides slow aging, and good low temperature performance.

Application: The theory behind SMA is to maximize the interaction and contact among the coarse aggregate fraction in an asphalt hot mix. Asphalt cement and finer aggregate portions provide the mastic that holds the stone in close contact. Typical mix design will generally have 6.0 to 7.0 percent medium grade asphalt cement (or polymer modified AC in some instances), 8 to 13 percent filler, 70 percent minimum aggregate greater than 2 mm (No 10) sieve, and 0.3 to 1.5 percent additives/fibers by weight of mix. Fibers are generally used to stabilize the mastic and this reduces the drain off of binder in the mix. Voids are normally kept between 3 to 4 percent. Maximum particle sizes range from 5 to 20 mm (0.2 to 0.8 in) depending on the country. The 0/11 mm (.43 in) size seems to be most common in Germany and many other countries in Europe. Table 5 presents some examples of the European SMAs, and also include recommended composition of SMA mixes for use in the United States [18,19].

Mixing, transportation, and placement of SMA uses customary equipment and practices with some variations. For example, higher mixing temperature of about 175°C (347°F) is usually necessary because of coarser aggregate, additives, and relatively high viscosity asphalt in SMA mixes. Also, when cellulose or similar fibers are used, the mixing time has to be increased (possibly 10 to 20 seconds) to allow the proper mixing. Rolling begins immediately after placement to achieve density quickly before the mix temperature decreases significantly. Compaction is usually accomplished by use of 9 to 10.8 Mg (10 to 12 ton) steel-wheeled rollers. Vibratory rolling may also be used; however, caution is recommended as not to over vibrate [19].

Traffic Control: Roads may be opened to traffic soon after rolling is completed.

Cost: Reports from Sweden indicate a 10 to 12 percent higher first cost for SMA over typical dense graded asphalt hot mix. Reports from Germany indicate a 20 to 30

percent higher initial cost [18,19]. Based on the initial experimental projects, the cost of SMA mixes in the United States is estimated to be 15-30% higher than conventional HMA's.

Performance: The expected service life of SMA in Europe has been reported to be around 10 to 12 years, which is about 20 to 40 percent higher compared with conventional dense asphalt concrete. The Germans, who have nearly 25 years of experience and have laid some 20 million m² (24 million yd²) of this mix, report that SMA is very resistant to plastic deformation. European reports also rank SMA much better than normal dense mix with respect to shear resistance, abrasion resistance, cracking resistance, and skid resistance, and equal for noise generation. Future evaluation of SMA experimental projects will provide information on the effectiveness of these mixes in the United States.

TABLE 5. COMPOSITION OF U.S. AND EUROPEAN SMA MIXES

Country	U.S. *	Germany	Sweden	Denmark	Norway
Type	0/11	0/11	0/12	0/12	0/11
Sieve size	% passing				
mm (in/No)					
19 (5/8)					
12.5 (1/2)	85-95				
11.0 (7/16)		90-100	95	93	80-100
9.5 (3/8)	60-75				
8.0 (5/16)		50-75	38-50	53	47-64
5.0 (No. 4)	25-34	30-50			
4.0 (No. 5)			30	28	30-45
2.36 (No. 8)	18-24				
2.00 (No. 10)		20-30	20-26	18-28	20-32
0.33 (No. 50)	12-15				
0.09 (No. 175)		8-13		4 min.	
0.075 (No. 200)	8-12		10		9-14
Asphalt (% of mix)	6-7	6.5-6.8	6.5-6.8	6.5-6.9	6.3
Fibers (% of mix)	cellulose(0.3) mineral(0.4)	cellulose (0.3)	cellulose(0.3) mineral(0.5)	cellulose (0.25)	

Note: Modified (polymer and elastomer) asphalt cements are used on many projects in Europe. When used modifiers are usually applied in the amount of 5-7% by weight of binder. * As recommended by Office of Engineering Applications, FHWA.

Limitation: Initial cost of SMA mixes is higher than dense mixes. There are some concerns about the initial skid resistance characteristics of this mix due to the high asphalt content.

Proprietary SMAs in Europe

Other SMA products in Europe include: Stabinor produced by Skansa AB and Viacotop produced by the paving contractor NCC, (Sweden) [18].

Thin and Very Thin Surfacing Systems in Europe

These systems are gap-graded and spread in layers of 10 to 25 mm (0.4 to 1 in). These systems are widely used in France, where they compete with modified slurries, OGFCs, and chip coats for surface rehabilitation. Most of these systems are proprietary and are designed to satisfy the French Ministry of Transport requirements for thin and very thin asphalt concrete overlays.

Purpose: These applications provide skid resistant, low noise surfaces and may also be used to eliminate shallow ruts and minor surface irregularities.

Application: Typical mix designs for high traffic roads will have 5.0 to 6.5 percent conventional or polymer modified asphalt cements, 0/6 to 0/10 mm gap-graded aggregate and about 1.5 to 3 percent filler. The finer grading is applied mainly in urban settings; the resulting texture is a good compromise between surface friction and tire noise. Mixes usually contain 12 to 20 percent crushed sand and are applied at a rate of 30 to 50 kg/m² (16 to 27.1 lb/yd²). In order to obtain a high macrotexture, the grading curves have a discontinuity (e.g., the 0/10 mix has a 2/6 mm gap). Some mixes contain organic fibers to improve the adhesion of the mortar and to allow a larger proportion of asphalt. The difference between thin and very thin mixes lies in the percentage of coarse aggregate and the proportion of binder. Very thin mixes have higher proportion of coarser aggregate and lower binder content. Table 6 presents characteristics of three of the French thin and very thin mixes [18, 20, 23].

A tack coat is applied prior to mix placement, which plays a dual role of waterproofing of the existing surface and tacking of the wearing course. The choice of the binder is mainly linked to traffic volumes. A polymer asphalt emulsion is usually selected for high traffic roads. The application rate of emulsion varies between 0.5 and 1 kg (.227 to .454 lb) depending upon the condition of the existing pavement.

While these mixes are usually applied using conventional mix-laying devices—i.e., spreaders, finishers, compactors—some modifications have been made by individual contractors/manufacturers.

TABLE 6. COMPOSITION OF THIN AND VERY THIN FRENCH MIXES

System		Microvia E	Enrovia		COLRUG
Type		0/6	0/6	0/10	0/10
Sieve Size		% passing			
mm	(in/No) *				
10	(1/2)			95	95
6.3	(1/4)	93	95	20	17
4.0	(No. 5)	32	22		
2.0	(No. 10)	26	22	20	17
Filler		9	2	1.5	2
Asphalt (% of mix)		6.6	6.4	5.5	5.4

Note: (1) Microvia is a thin (15-25 mm) system, whereas Enrovia and COLRUG are very thin (15 mm) systems, (2) Modified asphalts account for most of the very thin applications.

* Approximate

Traffic Control: Roads may be opened to traffic as soon as rolling is completed.

Cost: These mixes often cost 50% more than chip seals in France. The incorporation of an additive increases the cost by about 20 to 30%.

Performance: Some of these surfacings have been in use for about 6 years and have been applied to pavements having to carry heavy traffic (up to 2,400 trucks per day per direction).

Other Proprietary Thin Surfacing Systems in Europe

Some of the other patented systems in Europe include Permflex and Accoduit [18,21].

U.S. Thin Dense Mixes

Many agencies have developed specifications for thin dense grade HMA mixes for use on low to moderate volume roads. The application and effectiveness of these thin (25 mm or less) mixes on higher volume roads has not been a frequent practice. Thin HMA overlays were one of the SPS-3 techniques. Under this experiment 81 test sections were constructed using the State's standard thin hot mix overlay

specifications. Thicknesses of these overlays varied from 19 to 37.5 mm (3/4 to 1½ in). A recent National Asphalt Pavement Association report on "Thin Hot Mix Asphalt Surfacing" includes some information on thin (25 mm or less) HMA mixes [24].

SUMMARY

Pavement performance depends on its structural and functional conditions. The structural condition depends on the bearing capacity of the pavement and subgrade. Functional condition of the pavement describes how "good" the road is in terms of ride quality, user costs, and safety. Ride quality and associated user costs depend on the roughness of the pavement, and safety depends on qualities like skid resistance, permanent deformation, pavement color, and light reflection characteristics. Other important functional qualities may be tire-pavement noise emission, and tire wear. Rehabilitation techniques that can improve these functional conditions and rejuvenate or retard the effects of environmental aging and weathering of the pavements may offer a relatively low life cycle cost and improved overall performance and should be considered to effectively extend the total service life.

Conventional surface seals, treatments, and thin hot mix overlays have been used in the U.S. for a long period. However, their use on roadways with higher traffic volumes is rather limited. Some of the reasons for lack of use are:

- Anticipated short life expectancy (many times because of inattention to proper design and construction principles).
- Vehicular damage (in case of chip seals).
- Traffic disruption during construction (use of emulsions requiring a cure period).
- Lack of cost and performance data (inadequate exchange of information among users).
- Improper usage (inadequate existing pavement evaluation and condition).
- Absence of research to improve conventional practices.

Experience in other countries (particularly Europe) indicates that many of the above problems can be overcome by the use of additives/modifiers and attention to proper design and construction techniques. Use of rehabilitation techniques which employ engineered binders is slowly being adopted in the United States. One type of modified slurry seal (microsurfacing) which has been used in the United States has shown promising results when applied for certain functional type pavement distresses.

Several of the treatments have also been placed at various test sites around the United States and Canada under SHRP SPS-3 experiment to further evaluate the effectiveness of these techniques.

This report includes examples of surface rehabilitation techniques employed in United States and various European countries (see table 7 for summary). The purpose is not to promote any one technique but to highlight composition and use of the technology. The existing knowledge, especially in the area of enhanced surface rehabilitation construction techniques, engineered binders, and thin surfacing will hopefully lead to an era where construction of economical, high performance, pavement surfaces will become a more common practice, thus, providing the pavement managers increased flexibility in meeting their pavement needs and managing their limited budgets.

TABLE 7. SUMMARY OF SURFACE REHABILITATION TECHNIQUES

CONSTRUCTION TYPE	DESCRIPTION (thickness)	USES
1. Thin Seals		
Fog Seal	Diluted emulsion	Renews and enriches oxidized surface; seals minor cracks; prevents raveling; provides shoulders delineation.
Sand Seal	Emulsion with sand cover. (2-5 mm)	Same as fog seal, except that it does not provide the same level of delineation. Provides surface friction.
Slurry Seal	Mineral filler, well-graded fine aggregate, emulsion. (3-9.5 mm)	Same as fog seal. Also seals, fills minor irregularities. Improves surface friction with proper aggregate.
Micro-surfacing	Mixture of polymer modified emulsion, fine aggr., and additives. (6.3-12.5 mm)	Provides minor leveling; fills non-plastic ruts; restores surface friction. Also used to improve flushed surfaces.
2. Chip Seal Coats		
Single and multiple chip applications	Asphalt with aggregate cover. (6.35-37 mm)	Seals against entrance of moisture and air; seals low intensity fatigue and block cracks; renews weathered surfaces; improves surface friction.
Sandwich Seal	Double aggregate layers with one layer of asphalt. (6.35-19 mm)	Same as single application chip seal. Provides increased life which is typically the same as a double chip seal. Seals flushed surfaces.
Cape Seal	Single chip seal topped by a finer slurry seal.	Provides a denser surface with no loose chips. Improves surface friction and provides longer life.
Rubberized chip seal	Chip seal with rubber-asphalt.	Provides better crack sealing due to its flexibility. Can be used either as a SAM or SAMI.
European chip seal systems	Polymer modified emulsions. Pre-coated chips are often used. (6.35-19 mm)	Same as U.S. systems, but provide longer life because of modified binders. Pre-coated chips reduce tire noise and reduce/prevent windshield damage.
3. Thin HMA overlays		
OGFCs	AC mix with high proportion of single-sized aggregate. (19-25 mm)	Reduces potential for hydroplaning and improves visibility by reducing tire spray. Reduces tire noise and improves surface friction.
European OGFCs (porous asphalts)	Usually modified binders with lower asphalt content, coarse aggregate, and more air voids. Fibers are often used. (25-50 mm)	Same as U.S. systems. Thicker layers provide higher draining capacity and reduced tire noise over a longer period. Fibers and polymers prevent binder runoff and/or increase durability and aging resistance.
Stone Mastic Asphalt (European)	A gap-graded, densely compacted hot mix with additives. (25-40 mm)	Provides rut resistant surface. Also provides high wear resistance, slow aging, and good low temperature performance.
European plant mixed thin overlays	Gap-graded thin mixes with modified binders. (15-25 mm)	Provide surface friction, low noise surfaces.

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